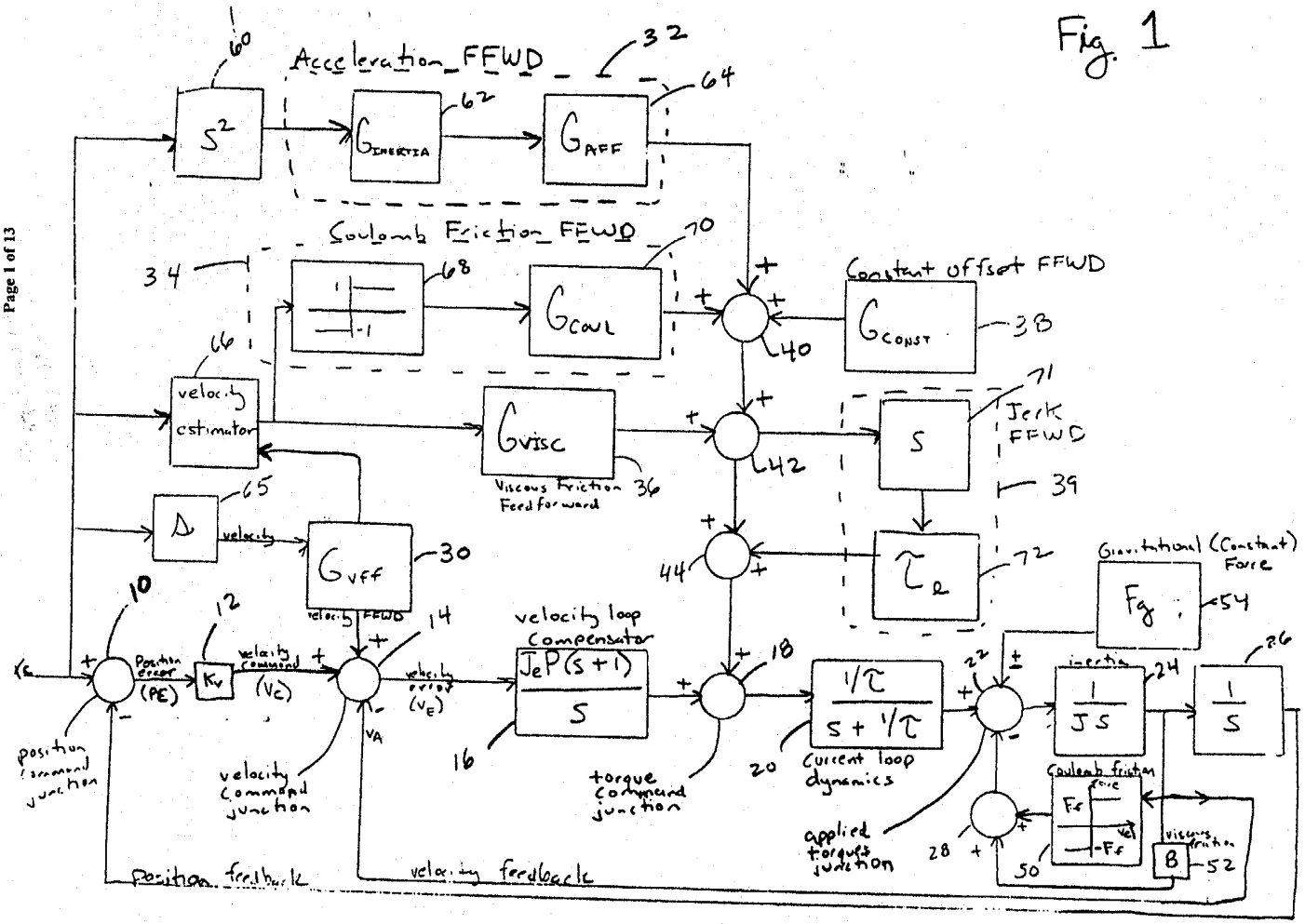
Title: Method and Apparatus for Tuning Compensation Parameters
Applicant: Stephen J. Yutkovitz
Serial No.: 10/017,021
Docket: 24914-134
Page 1 of 13

Fig. 1



Excitation Number
1.0
0.8
0.6
0.4
0.2
0
0
2,000
4,000
6,000
8,000
10,000
12,000
Condition Number

Fig. 2

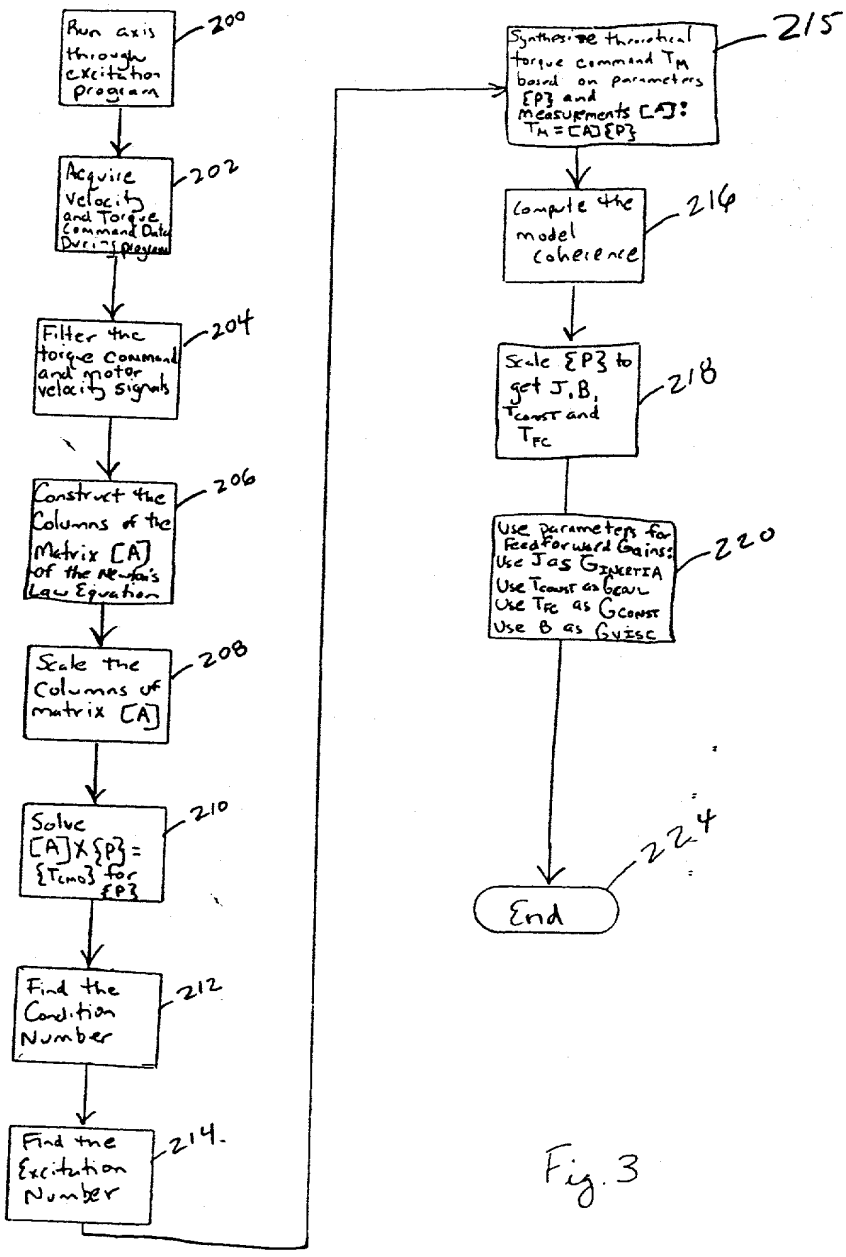

Run axis through excitation program
200
Acquire Velocity and Torque Command Data During Program
202
Filter the torque command and motor velocity signals
204
Construct the Columns of the Matrix [A] of the Newton's Law Equation
206
Scale the Columns of matrix [A]
208
Solve [A] X {P} = {Tcmd} for {P}
210
Find the Condition Number
212
Find the Excitation Number
214
Synthesize theoretical torque command TM based on parameters {P} and measurements [A]: TM = [A]{P}
215
Compute the model coherence
216
Scale {P} to get J, B, TCONST and TFC
218
Use parameters for FeedForward Gains: Use J as GINERTIA Use TCONST as GBIAS Use TFC as GCONST Use B as GVISC
220
End
224

Fig. 3

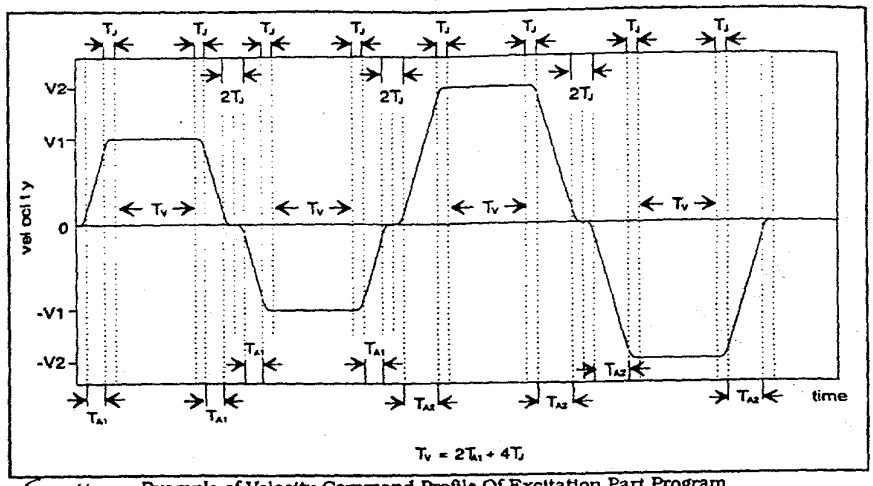


Fig. 4 - Example of Velocity Command Profile Of Excitation Part Program

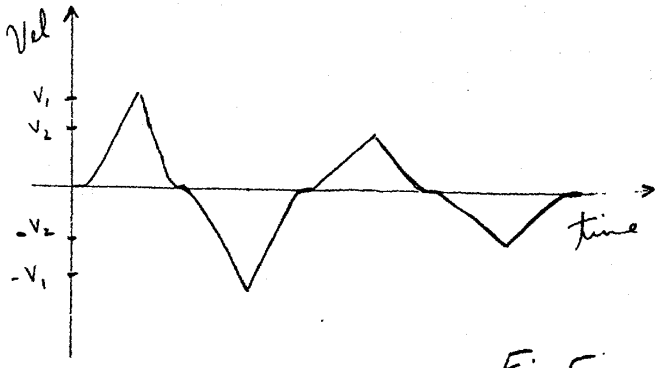


Fig. 5

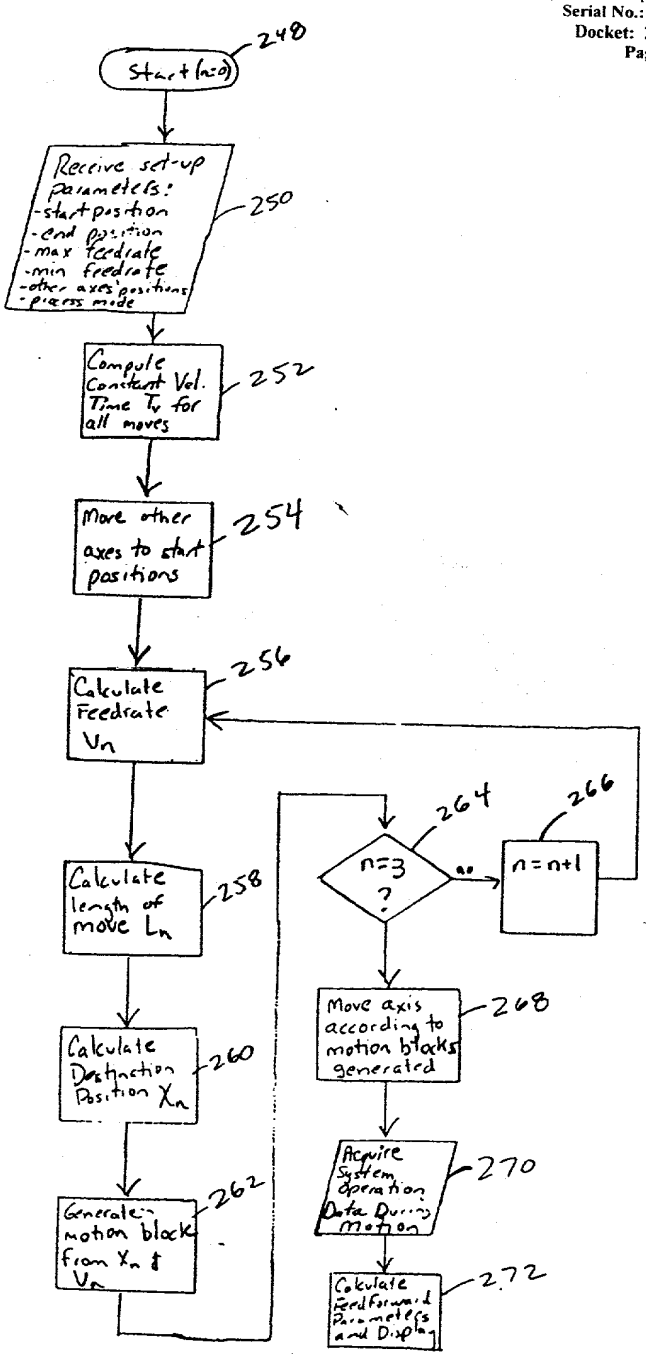

Start (n=0)
248
Receive set-up parameters:
-start position
-end position
-max feedrate
-min feedrate
-other axes positions
-process mode
250
Compute Constant Vel. Time T_v for all moves
252
Move other axes to start positions
254
Calculate Feedrate V_n
256
Calculate length of move L_n
258
Calculate Destination Position X_n
260
Generate motion block from X_n & V_n
262
n=3 ?
264
no
n=n+1
266
Move axis according to motion blocks generated
268
Acquire System Operation Data During Motion
270
Calculate Feedforward Parameters and Display
272

FIG. 6

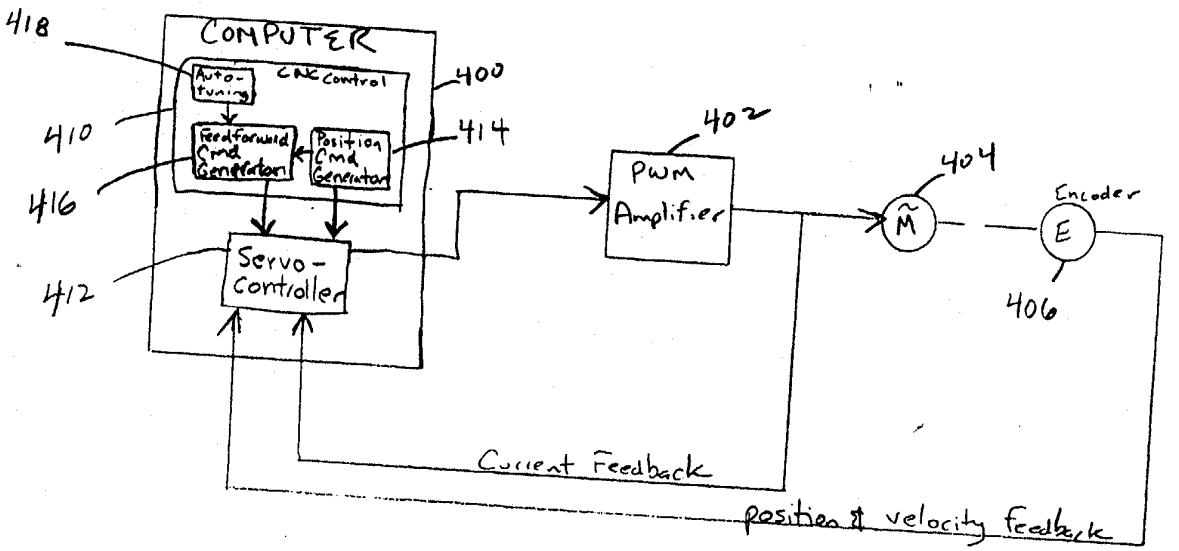

418
COMPUTER
Auto-tuning
CNC control
400
410
Feedforward Cmd Generator
Position Cmd Generator
414
402
PWM Amplifier
404
416
Encoder
Servo-Controller
412
406
Current Feedback
position & velocity feedback

Fig. 7

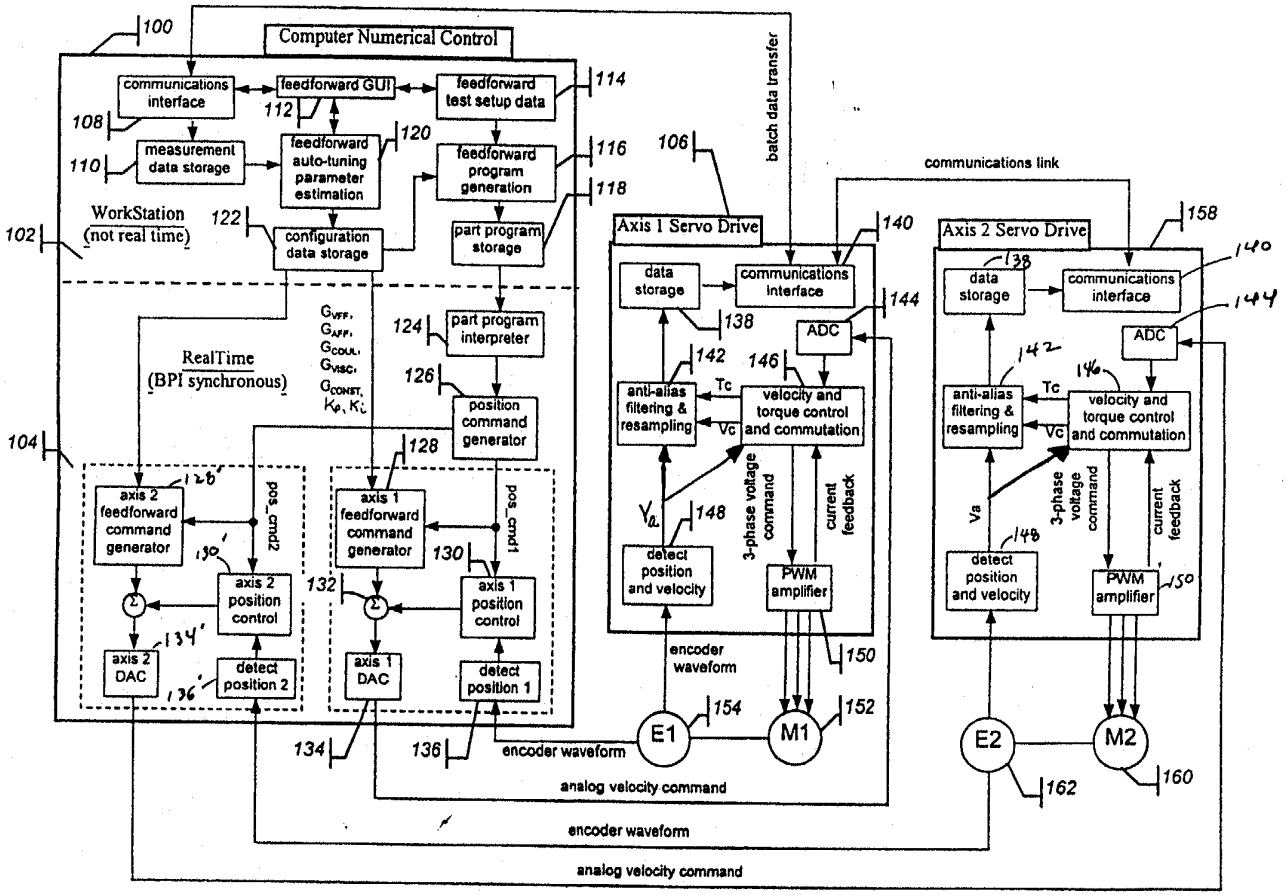

100
Computer Numerical Control
communications interface
feedforward GUI
feedforward test setup data
108
112
114
measurement data storage
feedforward auto-tuning parameter estimation
120
110
feedforward program generation
116
118
WorkStation (not real time)
122
102
configuration data storage
part program storage
RealTime (BPI synchronous)
G_{VFF}, G_{AFF}, G_{COUL}, G_{VISC}, G_{CONST}, K_P, K_I
124
part program interpreter
126
position command generator
104
128
axis 2 feedforward command generator
axis 1 feedforward command generator
pos_cmd2
pos_cmd1
130'
130
132
axis 2 position control
axis 1 position control
134'
axis 2 DAC
axis 1 DAC
136'
detect position 2
detect position 1
134
136
encoder waveform
analog velocity command
encoder waveform
analog velocity command
batch data transfer
106
communications link
Axis 1 Servo Drive
Axis 2 Servo Drive
140
158
data storage
communications interface
138
144
ADC
142
146
anti-alias filtering & resampling
Tc
Vc
velocity and torque control and commutation
V_a
148
3-phase voltage command
current feedback
detect position and velocity
PWM amplifier
150
encoder waveform
154
152
E1
M1
E2
M2
160
162

Fig. 8

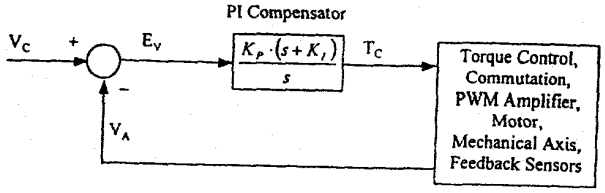

PI Compensator
V_C
+
E_V
$\frac{K_P \cdot (s + K_I)}{s}$
T_C
Torque Control, Commutation, PWM Amplifier, Motor, Mechanical Axis, Feedback Sensors
−
V_A

Fig. 9

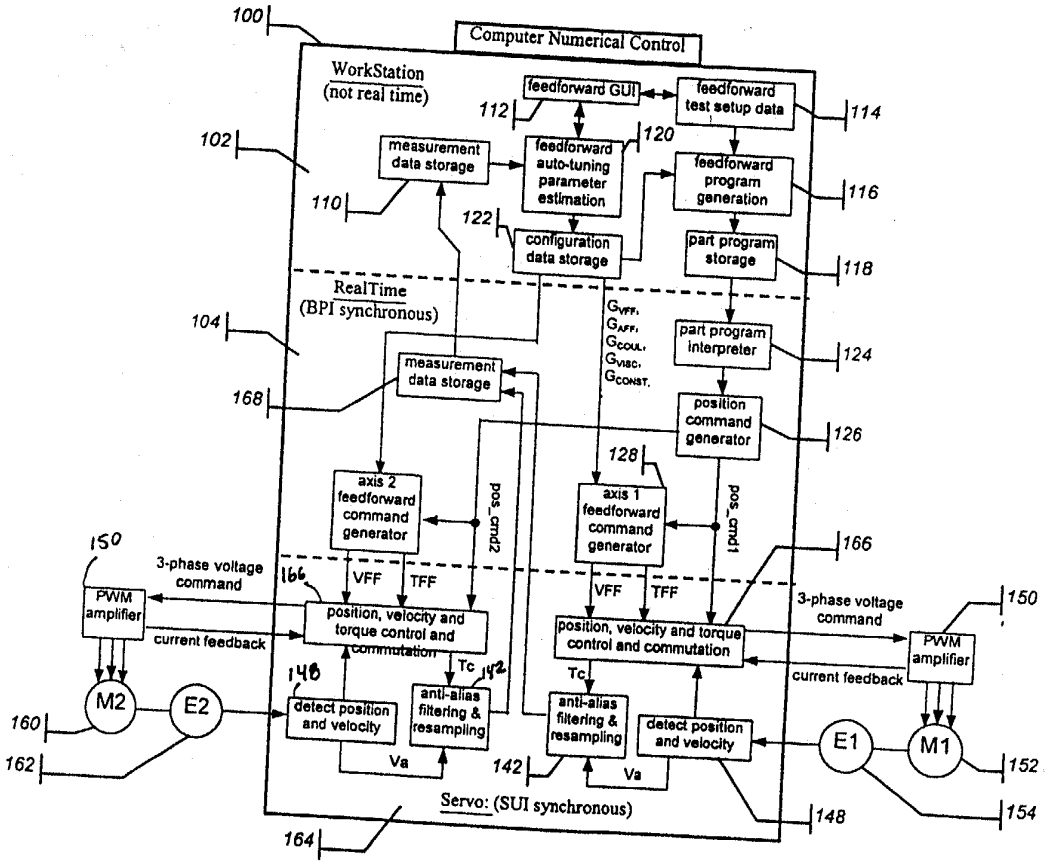

100
Computer Numerical Control
WorkStation
(not real time)
feedforward GUI
112
feedforward test setup data
114
102
measurement data storage
110
feedforward auto-tuning parameter estimation
120
feedforward program generation
116
122
configuration data storage
part program storage
118
RealTime
(BPI synchronous)
104
G_{VFF}, G_{AFF}, G_{COUL}, G_{VISC}, G_{CONST}
part program interpreter
124
measurement data storage
168
position command generator
126
128
axis 2 feedforward command generator
pos_cmd2
axis 1 feedforward command generator
pos_cmd1
166
150
3-phase voltage command
VFF
TFF
PWM amplifier
position, velocity and torque control and commutation
current feedback
Tc
146
142
anti-alias filtering & resampling
detect position and velocity
Va
M2
E2
160
162
E1
M1
152
154
Servo: (SUI synchronous)
148
164

Fig. 10

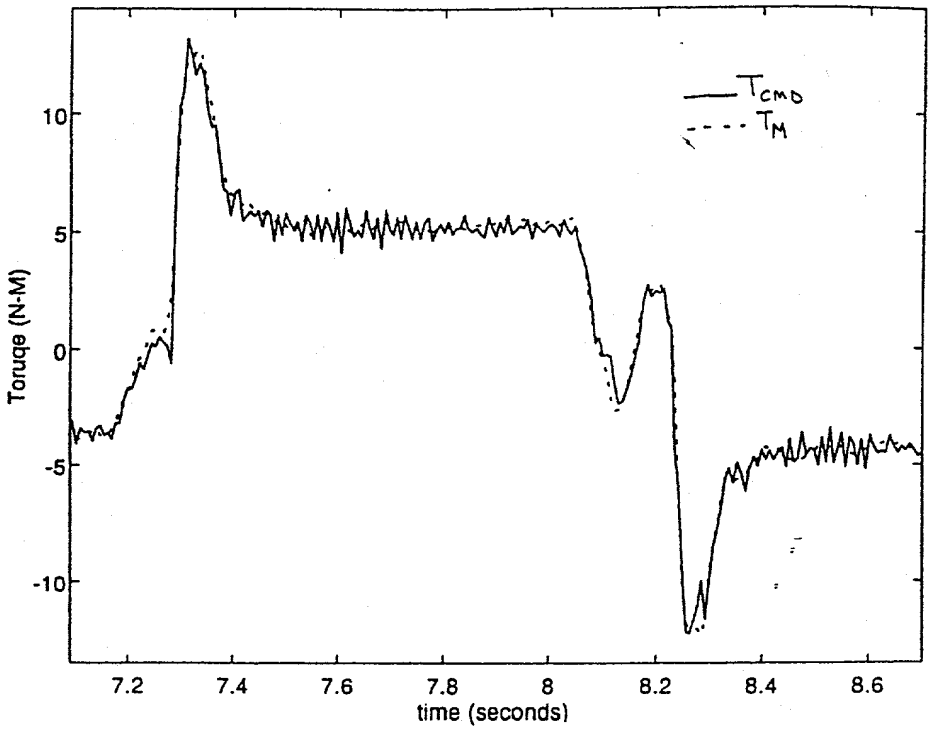


FIG. 11

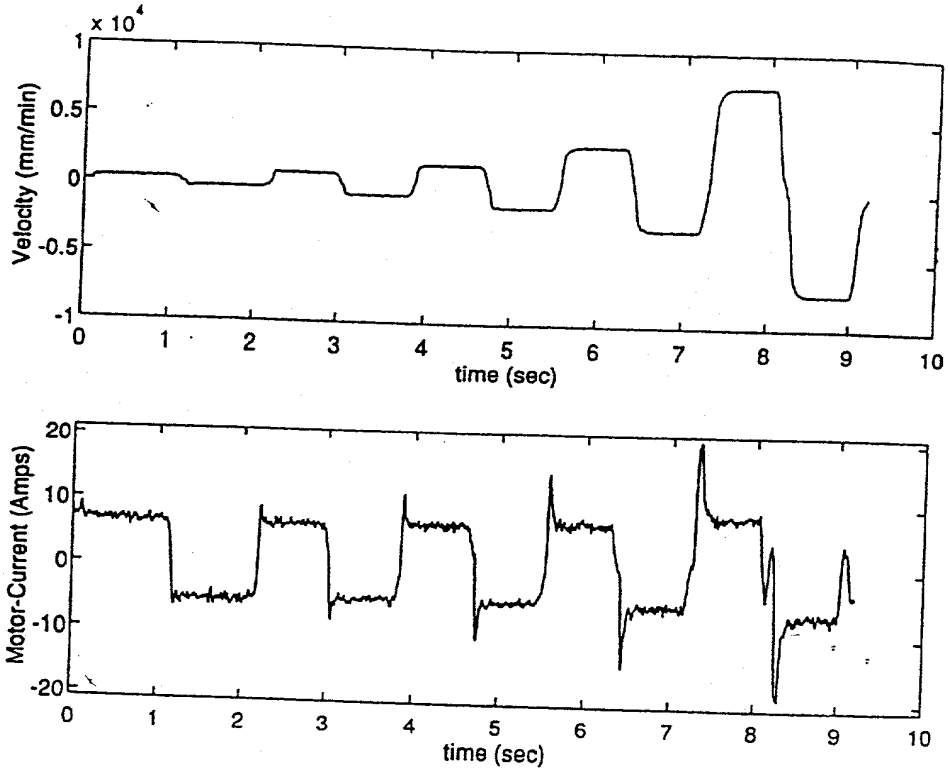

x 10^4
1
0.5
0
-0.5
-1
Velocity (mm/min)
0
1
2
3
4
5
6
7
8
9
10
time (sec)
20
10
0
-10
-20
Motor-Current (Amps)
0
1
2
3
4
5
6
7
8
9
10
time (sec)

Fig. 12

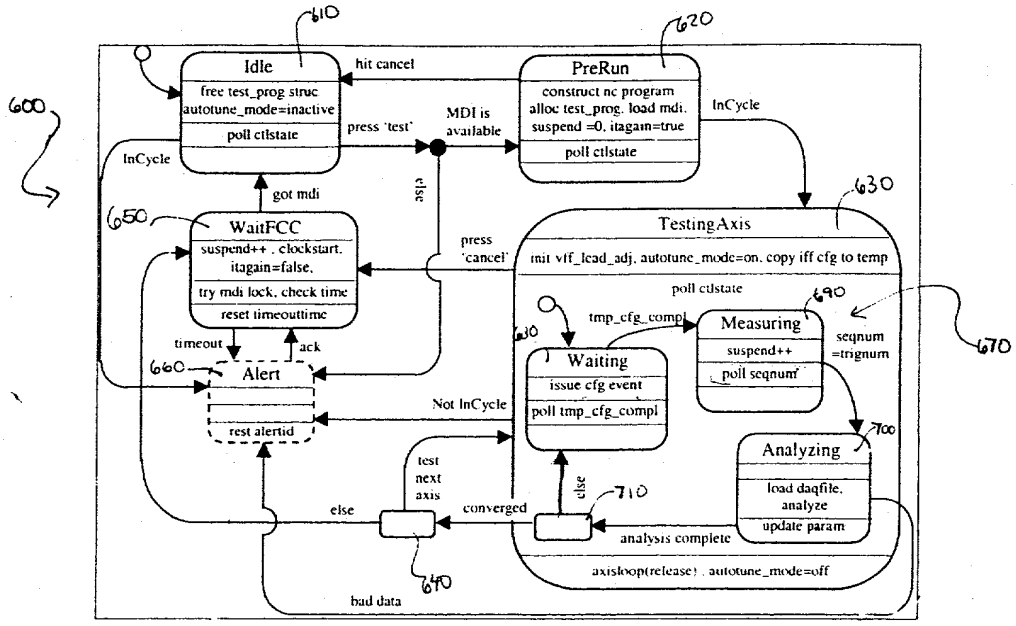

600
610
620
630
640
650
660
670
680
690
700
710
Idle
free test_prog struc
autotune_mode=inactive
poll ctlstate
hit cancel
PreRun
construct nc program
alloc test_prog, load mdi,
suspend =0, itagain=true
poll ctlstate
press 'test'
MDI is available
InCycle
got mdi
else
WaitFCC
suspend++, clockstart,
itagain=false,
try mdi lock, check time
reset timeouttime
timeout
ack
Alert
rest alertid
press 'cancel'
TestingAxis
init vff_lead_adj, autotune_mode=on, copy iff cfg to temp
poll ctlstate
tmp_cfg_compl
Measuring
suspend++
poll seqnum
seqnum =trignum
Waiting
issue cfg event
poll tmp_cfg_compl
Not InCycle
Analyzing
load daqfile, analyze
update param
analysis complete
test next axis
else
converged
else
bad data
axisloop(release), autotune_mode=off

FIG. 14

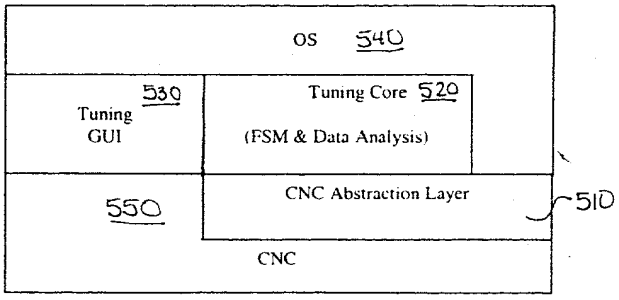

OS 540
Tuning GUI 530
Tuning Core 520
(FSM & Data Analysis)
550
CNC Abstraction Layer
510
CNC

FIG. 13